Biotechnology and Third World Farming Systems*

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BIOTECHNOLOGY AND THIRD WORLD FARMING SYSTEMS[1]

Introduction

Agriculture is on the verge of a technological revolution that will transform farming as much or more than any other group of technologies introduced to the farmer. Propelling this "biorevolution" in agriculture are the dramatic new advances in cellular and molecular biology that have been achieved in the research universities of the developed countries. Yet the social and economic implications of these new techniques for manipulating living organisms are only beginning to be understood (see Appendix 1). The importance of the new biotechnologies is such that decisionmakers in the Third World countries (TWCs) must develop strategies to ensure that their countries are not once again left hopelessly dependent on technology that must be imported from abroad at exorbitant prices. Action must be taken quickly because biotechnology and, generally, the basic biological sciences are advancing very rapidly. It is said by biologists that within ten years the entire human genome will be mapped (Gefter 1984)--a crucial step in engineering human beings. Clearly, we are only glimpsing the dawn of the biorevolution.

This document will provide an overview of the structure of the biotechnology industry in the developed countries (DCs) and then proceed to an analysis of the areas of potential impact on the TWCs. The initial section briefly documents the growth of the U.S. biotechnology industry. The U.S. is the focus because of its tremendous size and importance as the world pacesetter in biotechnology. The trend to privatize research results not only in the U.S., but in all advanced industrial countries could lead to an environment in which LDCs are unable to secure access to information important to the success of their national biotechnology efforts.[2] The final section will outline the types of policies LDCs can undertake to ensure their participation in the biorevolution on their own terms and not those dictated by outside entities such as the transnational chemical/pharmaceutical companies (TNCs). It must be recognized from the outset that a country desiring to participate actively in the biorevolution and not merely as a passive recipient must be willing to make difficult investment decisions and persevere.

Biotechnology is an array of tools that can be applied in a number of industries. In fact, any industry that involves living or dead organic matter could be affected. Thus, the industries prominently featured as being beneficiaries of biotechnology include: energy, chemicals, pharmaceuticals, waste management, and agriculture. Each of these industries is carbon-based and, in fact, biotechnology will contribute to the greater interlinkage of these industries. Thus, developments in one industry will affect the other industries. For example, suppose there is research success in fermenting energy from agricultural wastes. This would impact the energy sector and the economics of food production. There are numerous and complex interlinkages in these industrial branches and biotechnology provides techniques for addressing problems in each of these various industries.

The new scientific techniques that are included in biotechnology offer mankind the possibility of controlling and directing evolution itself (Rifkin 1983). There can be no doubt that biotechnology will make agriculture more productive than ever. Yet increased productivity is not an end in itself. Will this increased productivity benefit those too poor to be able to purchase the output? And, as importantly, will those TWC agricultural producers who are among the world's poorest be able to take advantage of these newest techniques developed by Twentieth Century science? The answer to these questions depends on a number of variables outside the control of the biotechnologists.

This monograph will demonstrate the impacts will be contradictory--biotechnology could increase farmers' productivity, conversely it could operate to entirely displace the commercial demand for that identical crop. In the developed countries farmers will plant biotechnologically-engineered seeds at a moment which is selected by an optimization program run on their microcomputer linked via satellite or telephone to an on-line data base. Increasingly, the providers of these services will shift from public agencies (departments of agriculture or public universities) to commercial entities (for-profit corporations) many of which will be transnational in scope.(3) What will TWC agriculture look like in the year 2000?

It is necessary for me to briefly state my personal position on the desirability of the coming "biorevolution." For TW biotechnology could be devastating by displacing export markets, displacing peasant farmers by creating new commercial farms, and increasing TW dependence on transnational corporations. The other possibility is the TWCs do everything possible to embrace biotechnology and adapt it to their unique needs. Biotechnology can be done at many levels from capital-intensive to labor-intensive. Irregardless, Third World laboratories will be the front lines in the struggle to overcome dependence. At least some TWC problems can be tackled using the techniques and tools developed by biotechnology and available in TWCs. It would be a certain mistake to attempt to mimic the research and activities underway in developed countries without developing a well planned <u>realistic</u> action program. The potential of biotechnology is best summed up by the Chinese character for opportunity--an amalgamation of the characters for danger and reward: Both exist in biotechnology.

Any productive force of the power and magnitude of biotechnology will necessarily have tremendous influences and impacts on social systems. There will be winners and losers, but no group is necessarily "fated" to be a loser. Being a loser will depend on the outcomes of the strategies a group, country, or group of countries adopt to ensure that they secure their rightful share of the benefits. It should be born in mind that choosing not to participate in the biorevolution is not a viable strategy because the impacts cannot be avoided. The biorevolution will affect even the most isolated societies.

The beauty of biotechnology is that it has many levels of sophistication from the ultrahigh technology of the MIT biology department with its multi-million dollar budget to the family-size tissue culture laboratories of Vietnam (Uyen 1984). Many of the ultrasophisticated modern techniques can be reduced to relatively low cost operations without losing all possibility of success. Clearly, U.S. research laboratories and family-size tissue culture laboratories are aiming at very different goals, but this is precisely the point--TWCs must aim at targets that are within reach--the choosing of achievable targets is of central importance.

The Agricultural Biotechnology Industry in the Developed Countries

Investments in agricultural biotechnology came somewhat later than those in the biomedical area. In the period from 1979 to 1983 plant molecular and cellular biologists followed their medical colleagues and quickly became involved in forming new biotechnology firms (NBFs) with names such as, Advanced Genetic Sciences, Calgene, Plant Genetics, DNA Plant Technologies, Phytogen, Molecular Genetics, and Sungene. Other new biotechnology firms

(NBFs) such as Cetus, Genentech, Biogen, and Biotechnica International also launched certain agriculturally-related R & D programs. Another group of companies the large multinational agribusiness pharmaceutical/chemical companies (MNCs) with big investments and large marketing networks in agricultural chemicals and seeds also showed interest in what biotechnology could do for their operations.

As has been documented for the general biotechnology industry (Kenney forthcoming), the agricultural biotechnology industry began on the basis of the expertise university professor had developed in their campus laboratories. Agricultural scientists whose research had been funded by U.S. government agencies were approached by or approached entrepreneurs who were seeking the scientific expertise necessary to launch NBFs. In return for his services the university scientist, usually a senior professor, receives a significant equity position in and was put on retainer of the fledgling company. With this partnership the new company is launched and the quest for capital and products commences.

Capital is a critical requirement for these companies because the major products of biotechnology will not be immediately available. In fact, the typical company will operate for five to ten years before producing its first important product.[4] In 1980 the start-up costs for a non-agricultural NBF's first three years were estimated to be approximately $10-12 million and a staff consisting of at least 25 Ph.Ds. The scale-up of R&D to production and the necessary marketing network could be an order of magnitude more expensive (Schneider 1980:72). However, some agricultural operations have been launched with less investment. For example, Molecular Genetics, Inc., a prominent agricultural NBF had only 114 employees and assets of $33 million (Molecular Genetics 1984).

Obviously, such sums of capital are not available to the average professor and securing sufficient funding has required the NBFs to tap a number of financial sources. The initial source of capital for many NBFs were the venture capital funds that specialize in providing start-up funds to new companies in return for a share of the new company's equity. These venture capitalists evaluate the company's business plan and assist in the recruitment of the necessary managers, lawyers, and accountants that will provide the managerial base so necessary to ensure the young companies survival. These financiers have no commitment to the company and are investing for the sole purpose of securing a large capital gain upon sale of their equity interest.

The venture capitalists, however, cannot fund an NBF alone and it must seek other fund sources. The two most common sources of increased capital are stock offerings and research contracts. Stock offerings induce the public to accept part of the risk of the company on the promise of stock appreciation. Research contracts between MNCs and NBFs are another method of securing the needed funds to pay for research. The NBF is forced to sign such contracts because having no products it has few alternative sources of capital. The goal of the MNC is to secure a genetically engineered product or scientific information from the smaller company. The research contracts signed with MNCs place the NBF in the uncomfortable position of selling the knowledge crucial for its survival to its competitors.

The key to the NBFs' success is the personnel that it retains on staff and its consultants in the universities (for example, Table 1 indicates the members of MIT's biology department linked to small biotechnology companies.

The MNCs in only very few cases have managed to recruit scientists of comparable quality to those NBFs have secured. Robert Luciano, now president of Schering-Plough, said when speaking of Biogen's scientists, "You just couldn't hire people like that to work in industrial settings." (Bylinsky 1980:152). A similar situation exists in agricultural biotechnology where the small start ups have succeeded in hiring top scientists. For example, Table 2 identifies Agrigenetics' university scientist consultants.

A unique feature of the U.S. biotechnology scene has been the rapid development and important role of the NBFs. The key institution in the formation of the NBFs has been the university--the location of both the trained personnel and the necessary knowledge. The dependence of these companies on basic research skills is demonstrated by the fact the the NBFs have clustered around the major biological research universities of Boston and the San Francisco Bay Area, with the agricultural biotechnology firms clustered in Davis, California and Madison, Wisconsin.

The University and Agricultural Biotechnology

The biotechnology industry was born in molecular biology research laboratories located in research universities and medical schools. Thus, "basic" biological research had emphasized medical applications and the majority of the U.S. agricultural universities had not channeled funds into basic research, especially in plant molecular and cellular biology. As a result there were few plant molecular biologists available in the agricultural universities and, in fact, many of the top "basic" plant biologists were located in universities not traditionally associated with agriculture such as Harvard University, the Massachusetts Institute of Technology, Stanford University, California Institute of Technology, and Rockefeller University.

This lack of expertise in plant molecular biology has contributed to the shortage of personnel as companies have rushed to hire agricultural biotechnologists.

The university is a very special institution in any society because it trains the skilled labor force of the society and does much of the basic research from which new productive forces are derived. The information derived from this research has traditionally been communicated openly to all interested in acquiring the knowledge. This openness has provided access to science that is unavailable from private companies. The free flow of information and lack of pecuniary motive has allowed scientists and students from any country to come and learn in a relatively open and free environment and has provided a medium for technology transfer to TWCs.

The impending biorevolution in agriculture has had numerous implications for the agricultural universities. First, large numbers of the best researchers in areas of potential agricultural applications have been lured to join biotechnology companies. Many of the remainder of the professors that have not left the university entirely have joined company scientific advisory boards and have received stock options and other benefits. Thus, at the professorial level many researchers are now linked by financial bonds to private enterprises. In some cases it may no longer be clear whether a professor from a U.S. university is speaking as a professor or as a corporate owner (Kenney forthcoming). President Giamatti (1982:1279) of Yale University summarizes this contradiction thus:

> The burden of mounting a teaching program and two separate research programs (one in the company and one in the university) where the results of one research program are to be widely disseminated and the results of the other may have to be kept secret in the pursuit of commercial success, is more than even the most responsible faculty member can be expected to shoulder.

The implication for LDCs seeking expertise in agricultural biotechnology are clear--at this time in the U.S. especially, but in most developed countries (and in many developing countries) scientists may suffer from conflicts of interest as corporate employees.

University administrations have responded to the phenomenon of university professors as corporate principals by attempting to secure corporate monies for the university and capturing overhead. So, for example, the University of Illinois created a center for plant biology to be funded by Sohio, the large oil multinational.(5) Sohio's researchers will have access to this center and will have special patent privileges. In this particular case, for $2 million Sohio has purchased a "captive" agricultural research team in a publicly funded university. University administrators were involved in every aspect of the creation of the center and gave their blessing to this relationship. Other universities have allowed professors to receive funding from companies such as Agrigenetics and signed contracts containing provisions for the maintenance of trade secrecy regarding university-made discoveries.

If it be thought that U.S. institutions are alone in this rush to privatize public research, the case of the Australian National University (ANU) is instructive. Agrigenetics is patenting a new ANU-developed soybean variety that can fix up to thirty-five times as much nitrogen as currently available varieties. The ANU research team received from Agrigenetics $2.2 million in research funding over four years, in return Agrigenetics secured exclusive worldwide rights except in Australia to any varieties developed by the research team. The benefits of this variety is that the new soybean fixes more nitrogen thus less commercial nitrogen need be applied, there is less nitrogen runoff, and less stress on the soil structure (ANU Reporter 1984).

This recent development was made by random mutation methods, a less sophisticated biological technique--the new biotechnologies should provide even more advances. Will this new development or others be available to soybean growers in LDCs? The answer is obvious--only if they can pay for it.

In the publicly-supported agricultural universities plant breeders have traditionally bred crop plants and freely released their varieties for public use. The public role extended from basic plant research to the applications of the knowledge. However, recent criticisms have arisen that agricultural researchers are only involved in mere maintenance work in response to farmers' needs and not doing "basic," i.e., noncommercial research. This applied focus has until recently not been a topic of debate, but rather been hailed as a model upon which to build the agricultural systems. Now U.S. policy makers are questioning the model (Rockefeller Foundation 1983; National Academy of Sciences 1984).

The publicly-funded agricultural universities also are receiving new competitors in terms of which universities are doing plant-related research. Increasingly, universities such as Harvard, Washington, and Rockefeller are becoming centers for plant-related basic research. Over the next twenty years it seems likely that only the strongest public agricultural universities will remain important in plant biotechnology research. And, in fact, a recent report issued by the White House and the Rockefeller Foundation (1983), Science for Agriculture, advocates centralizing of all agricultural research, while encouraging agriculturally-related research in universities not traditionally associated with agriculture. This centralization could lead to a more easily managed and controlled research agenda, in which issues advocated by powerful groups such as farmers could be more easily ignored. There seems little doubt that the implementation of the new proposals will increase the role of the MNCs in determining the research agenda and, in fact, their spokesmen have lobbied strenuously this centralization (Hardy 1982).

The Multinational Corporations, Agriculture, and Biotechnology

The new biotechnologies emerged at a very propitious moment for the world's chemical/pharmaceutical companies, many of whom have been experiencing a pronounced profit dip (Kenney forthcoming:300) and a slowing of the rate of new drug and chemical discoveries (Steward and Wibberley 1980). For these MNCs biotechnology was a new technique promising to yield lucrative new commercial opportunities.(6) Biotechnology is an important technological spearhead in the ongoing drive by these MNCs to abandon commodity chemicals and move into specialty and agricultural chemicals. As an aspect of this strategy and to strengthen their position in agrichemicals the MNCs have been purchasing seed companies (Mooney 1979, Kloppenburg and Kenney 1983). The reason for these purchases are clear: The seed contains the DNA program that living plant follows, i.e., the seed contains all of the valuable traits of the grown plant such as stress tolerance, plant morphology, yield potential, and responses to agrichemical inputs. The importance of controlling the seed industry is that seed research may yield chemical-seed packages in which a farmer purchasing a seed could be locked into certain chemical proprietary chemicals, thus ensuring the company its all-important chemical market. For example, Ciba-Geigy markets a sorghum seed-chemical package in the Sudan. The seed is coated with a patented "safener" to protect it from Ciba-Geigy's patented herbicides (Farm Chemical 1979:55).

Seed company purchases are also justified on the basis that new biotechnological techniques will improve techniques for producing hybrids whose progeny are reproductively unstable and cannot be replanted by the farmer. This ensures that the farmer returns to the seed company annually for the seed and thereby creating a market. The best example of a company that successfully markets hybrid seed is Pioneer--a company that consistently has a very high return on equity (Kloppenburg and Kenney 1983). Finally, successful hybridization of wheat and rice may open enormous new markets for MNC seed subsidiaries.

Obviously, intense biotechnological research is going into creating new seeds. In addition to investment in seed company subsidiaries, MNCs are also making large investments in and funding agricultural research by the NBFs (see Table 3). For example, Monsanto has made major investments in a variety of product areas (see Table 4). In addition to investments in NBFs and university research MNCs are building large in-house research facilities (see Table 5). The MNCs feel that they must be at the forefront of biotechnology research due to its possible impacts on products they already market. Monsanto, Dupont, and the other MNCs are also aware that breakthroughs in biotechnology could make their products obsolete. For example, many companies are searching for a gene to clone into crop plants that will confer pesticide-resistance to crop plants.

The research agenda these corporate dollars are reinforcing in the world's research universities is one based on the necessity of making profits. Corporate support for biotechnological research is greatest in the U.S., but increasing numbers of scientists and universities in other countries are also receiving corporate support. This growing trend does not augur well for the role of these institutions in transferring knowledge to TWCs or for poor farmers who will be unable to purchase the new inputs from the university's corporate sponsors. In all likelihood, the products of biotechnology will be offered to LDCs for purchase at monopoly prices in a similar manner as occurs currently in the pharmaceutical industry. The manufacturing knowledge will either be hidden as a trade secret or patented and inaccessible for use by LDC producers. It should also be assumed that DC governments will assist in preventing LDCs from using the patented inventions.

The Biotechnology Industry in Developed Countries--A Summation

The creation of the biotechnology industry is the story of the privatization of publicly funded research--a process in which both professors and administrators took part. Even now, professors normally assumed to be working for the public good are, also, private employees. As a result of this new orientation professors may skew their research in directions favored by their private patrons. For other groups in society these directions may be less desirable. For example, will a researcher receiving Monsanto funds try to develop a new plant variety that has less need of herbicides? Or will that researcher develop plants that are Roundup-tolerant so as to enable farmers to use ever greater doses of Monsanto's proprietary herbicide, Roundup. Quite similarly, will corporate-funded university researchers examine techniques to increase yield without hybridization or will hybridization be the goal? The setting of research goals in biotechnology will become an increasingly important political and social issue.

The description in this section has focused on the developments in the U.S. In Europe and Japan the home MNCs have also been very active in conducting research and nearly all have signed contracts with U.S. NBFs. However, non-U.S. universities have not been quite as entrepreneurial as those in the U.S. European professors also have been more reticent to join companies. Professors in publicly supported Japanese universities are forbidden to join companies. Nevertheless, the entrepreneurial fever is also evident in Europe and Japan.

The scenario that this section has developed appears grim for developing countries wishing to develop expertise in biotechnology, but there are still methods of securing information and expertise. Perhaps, the most important aspect of this section is that it provides an understanding of the social arrangements that have evolved in the U.S. especially, and more generally, in the developed countries. The next section of the paper examines the effects the biorevolution will have on LDCs. The fact that biotechnology will have countless and contradictory aspects is acknowledged, but for the purposes of an orderly treatment the agricultural areas of greatest interest are divided into four areas: 1) plant genetic manipulation and crop improvement, 2) industrial tissue culture, 3) animal applications of embryology and genetically engineered products, and 4) the use of genetically engineered microorganisms to produce or displace agricultural products.

The Biorevolution in Third World Agriculture

As indicated earlier the biorevolution will have four major axes of impact on LDC agriculture and under each axis a number of specific products and processes are subsumed. In fact, in some cases biotechnology could have contradictory influences on the very same product. For example, a higher yielding soybean could be produced by one group of scientists and another research group could develop a more efficient single cell protein production process creating a commercial competition between the two protein production processes. It is necessary for every country to become more aware of the implications of the new technologies for its economy so as to take measures to position itself to benefit from the new opportunities and to undertake defensive measures where needed.

The biorevolution will not be immediate, but rather will unfold gradually as new products are developed and deployed in increasing numbers. For example, Genecol, an anti-scours vaccine for calves, is already available, while corn plants that fix their own nitrogen are at least five to ten years in the future (Fox 1984). This section, in describing the universe of possibilities, will discuss products currently available and others that will be developed in the much more distant future. Concomitantly, observations regarding the social impacts are extrapolated from studies of previous introductions of innovations and are meant to pose questions for policymakers. It is, perhaps, too early to supply answers.

The final concern addressed is the increasingly important role of private enterprise in the global biotechnology market. Can TWCs be assured that their agricultural needs will be met through the research financed and conducted by these companies? Moreover, even if products were produced to meet Third World needs, would the importation of these products be socially desirable? The problem of biotechnology being used to reinforce dependence and underdevelopment is posed starkly because of the tremendous possibility biotechnology represents for overcoming dependence.

Plant Genetic Manipulation and Crop Improvement

In agriculture, biotechnology's brightest promise is to provide techniques for increasing crop plant yields especially coarse grains and legumes which provide the bulk of the world's food. The success of modern plant breeding in increasing crop yields over traditional varieties is well-documented (Table 6).[7] An important example of the impacts of plant breeding success in TW environments has been the success of high yielding rice and wheat varieties in increasing production. However, in the last five years for the important grain crops, i.e., rice, wheat, and corn, there is reason to believe that decreasing returns to traditional plant breeding have been reached (Fox 1984).[8] Regardless of the actual facts about the rate of yield increase biotechnology is being touted as a method for drastically increasing the rate of growth in agricultural output. M. S. Swaminathan (1982), Director General of the International Rice Research Institute, lists the possible applications of biotechnology research to rice improvement in Table 7. Other research is underway to develop plants better able to survive on soils deficient in certain trace minerals. The various biotechniques provide a plethora of new tools with which applied plant scientists can produce new improved plants.

The Green Revolution was largely carried out by public or quasi-public institutions, such as, national breeding programs and the international agricultural research centers (IARCs). The motive of the research was not private profit, but rather increased food production. This is not to say that there were no other motives. It is very clear that the blocking of revolutionary movements was an important concern (Cleaver 1972). Irregardless, the fact that these institutions were public or quasi-public made them much more vulnerable to public pressure for changes in research agenda. The IRRI's shifting staff and resources to studies of upland rice and Azolla nitrogen fixation program in response to its critics is an example. The nonprofit status of the IARCs did not interfere with corporate objectives because seeds did not provide a very large market in TWCs.

Duing the last fifteen years the MNCs lack of interest in seeds began to change due to the establishment of plant variety protection laws. Plant variety protection provided breeders with patent-like rights to any varieties they developed by precluding other companies from selling exact copies of their varieties. This provided the needed incentive for agrichemical producers to join the seed industry and thereby complete a horizontal integration of non-durable farm producer goods inputs (Table 8).

The development of new biotechnologies has quickened the pace of seed company acquisition. As seen earlier in Tables 3 and 5 the MNCs have made major investments in agricultural biotechnology. These companies believe that biotechnology offers a tool to effectively wed their agrichemicals to the seed. This will not only secure synergies, but ideally would ensure that the farmer purchase an entire input package from the company. An important goal of this research trajectory is to develop plants entirely dependent upon application of a specific proprietary chemical.

Plant genetic engineering offers a number of possible research goals ranging from producing plants engineered so as to not require herbicides because they are very competitive with weeds to those engineered to require herbicides. The first research goal obviously is not as interesting to an herbicide manufacturer as the second. Thus, Monsanto, the producer of a \$500 million per year in sales molecule called Roundup, and Lasso, an over \$100 million per year herbicide, is investing tremendous sums to investigate plant herbicide-resistance. If the gene for Roundup-resistance can be successfully cloned in a plant (this was accomplished by Calgene last year) (Comai et al. 1983), then greater quantities of Roundup can be used on crops. In a more general way herbicide-resistance is becoming a research goal for increasing numbers of plant scientists.

Another important area of research in which biotechnology could assist is the development of economically efficient hybrid strains of rice and wheat. The reason the farmer adopts the hybrid seed is that successful hybridization can provide twenty or more percent yield increases. The quality of hybrids so attractive to industry is that the harvested grain cannot be replanted with the same results. Thus, the farmer must return annually for new seed, because the hybrid's progeny are not uniform, thereby guaranteeing an annual market. This is not to say that hybridization is bad. In a situation in which the farmer could be guaranteed access to low cost seed supplies, hybridization could provide increased yield, a desirable outcome. The problem is more complicated if the farmers are located in a TWC and the seed company is based in a developed country, because a dependency on imported seeds might be developed.(9)

Commercial hybridization has for the last thirty years been confined to corn and sorghum. Recent breakthroughs in rice through the discovery of cytoplasmic sterility and in wheat by the development of pollen sterilants are permitting the development of hybrids in those crops. The hybrid rice is especially important because within five years the International Rice Research Institute will be releasing varieties suitable for cultivation upon the ten million hectares now cultivating IR36 (Kenney 1984). The People's Republic of China already has 6 million hectares growing hybrid rice (Swaminathan 1982:971). It is not too early to explore the types of infrastructure that will be necessary to ensure the prompt regular delivery of the needed hybrid seed to the farmer--tardiness in delivery would be disastrous as the farmer will be unable to replant retained seed.

IRRI is not the only organization exploring the potentials for hybrid rice. Occidental Petroleum, through its Ring Around Seeds, and Cargill Grain Company have purchased rights to sell Chinese rice varieties in LDCs (Kenney 1984). If the hybrid rice market proves to be commercially lucrative, then it is likely that increased pressure will be applied to IRRI to remove itself from hybrid rice production and free distribution of improved germ plasm. This pressure could be exerted through the funding that IRRI receives from developed countries.(10)

The impacts of tissue culture research upon plant breeding will be enormous. Scientists may be able to develop HYVs that are tolerant of environmental adversity such as high soil aluminum content, salinity or waterlogging, to name only a few. This could have the impact of transforming formerly marginal agricultural lands into productive valuable land. These lands, however, are usually not without agriculturalists. It is likely that similar events will occur due to these new HYVs as occurred in the previous Green Revolution whereby entire groups of farmers and landless laborers were enclosed from the land because of the new seeds increased land values (Pearse 1980).

Biotechnology provides not only possibilities of crossing sexually incompatible plants, but also of speeding up the breeding process. This is important because it currently takes ten to fifteen years to provide a new variety to the farmer. The use of tissue culture can speed the reproduction cycle and reduce response times for the creation of new varieties. This is important because pests are constantly mutating against field crops and scientists must constantly develop new varieties. Thus, tissue culture can become an important addition to the traditional tools of plant breeders.

The Green Revolution was specifically directed towards food grains, but the biorevolution will also affect agroexport crops. Tissue culture can be used to clone plants such as trees that require long maturity periods making it possible to vegetatively propagate and reproduce elite trees in large numbers. These techniques are already being used for palms, agave, bamboo, orchids, coffee, sugarcane, banana, cacao, and plantains, among others. In many cases vegetative propagation technology is not overly sophisticated and can be undertaken by a relatively well-equipped laboratory in a TWC.

The application of these crop improvement techniques will be very important in assuring that TWC export crops are not displaced by substitutes produced in developed countries. As happened in the case of high fructose corn syrup based upon immobilized enzyme technology successfully competing with sugar in developed country markets.[11] The response of sugar exporting countries must be to decrease their production costs not only by decreasing costs of refining, but also by developing better cane varieties. Biotechnology offers a tool in this competition, as immobilized enzymes were the tool that the corn wet millers used to enter the sweetener industry.

As indicated earlier the new biotechnologies offer great potential for increasing the productivity of nearly any crop. However, the large potential increases in productivity carry with them social consequences which are not predictable in the abstract. If redistributive programs are not implemented simultaneously with the application of biotechnology the poorest will be the victims rather than the beneficiaries of biotechnology. The role of the MNCs in delivering the products of biotechnology may also pose problems for countries trying to develop national biotechnology programs. Very obviously, the next twenty years will be ones of tremendous technical change in agriculture and agroforestry production systems.

Genetic Erosion

The last ten years have led to an increased awareness among agricultural scientists of the erosion of the world's genetic resources (Jain 1982, Wilkes 1983). Genetic resources refer to the genetic variability that different plant varieties have encoded in their DNA. For example, the many varieties of corn have different qualities: yield, stature, pest resistance, moisture tolerance, etc. Those differences reflect differing capabilities of responding to environmental variation. The plant breeder used these qualities (genes) as raw material for the breeding process. Obviously, the larger the pool of varieties available the greater the inventory of traits available for breeders. When a greater number of varieties with different characteristics are planted, not only do you have more information, but also the total crop planted has greater resilience. As an example, if there is a drought, at least the drought-resistant varieties survive. The same is true regarding pest infestations. Conversely, the monoculture of a single variety creates a more fragile system in that if this variety succumbs to an environmental tort each of the genetically identical plants are affected posing the possibility of an epidemic.

The major centers of plant genetic diversity are located in the TW. Thus, TWCs are the source of genetic materials for the food we produce, export, and consume. The modernization of the TW agriculture is creating a situation in which single genetically uniform varieties are being sown over large acreages and displacing traditional varieties. The response to the problem of genetic erosion has been the collection and storage of traditional seed materials in germplasm repositories. However, in the last few years the preservation process has become politicized because TWCs are charging that these genetic resources are being collected, used in plant breeding in DCs, and the products are then resold to TWCs. TWCs are demanding if there is to be a free flow of germplasm (seeds) to developed countries, then the finished seeds should also flow freely (Mooney 1983)! The TWCs' position is that the current system is merely another method of exploiting the resources in the TW for the benefit of the MNCs. The response of the DCs has been that these genetic resources are the common heritage of all mankind.

The entire debate regarding genetic erosion has become increasingly bitter because the pending biorevolution has increased secrecy and the potential value of genetic information (Walsh 1984:148). Many TWCs are beginning to forbid germplasm collection within the nation, even as other countries such as Japan and China hasten to construct new and larger germplasm repositories. As for genetic erosion, it appears that this process is largely irrevocable. The final outcome of current trends could be that the TWCs currently possessing in situ germplasm resources will find that their genetic resources have disappeared and are only available from developed country storage facilities. Thus, those formerly genetically rich will have been transformed into those genetically poor--the wheel turns full circle.

Animal Husbandry

The biorevolution will not be confined to plants and, in fact, will probably initially have as great or greater impact on animal husbandry. There are three distinct areas in which biotechnology will impact animal production: the use of bacterially-produced hormones, new vaccines, and the new reproductive technologies. These techniques are, in principle, applicable to any animal, but the animals receiving the bulk of the research are cows, swine, and chickens. Animals important to TWC agricultural production such as camels, water buffalos, and llamas are receiving far less attention than even dogs or cats. This is because the owners of these pets have greater effective demand than the millions dependent on water buffalos or camels--and these technologies are being developed by for profit companies.

New techniques to control animal reproduction are already on the market in DCs. The animal having the largest market potential and receiving the greatest research attention is the cow. Bovine artificial insemination has been available for many years, but in the last ten years scientists have developed techniques for nonsurgically transferring embryos from one cow to another. This is coupled the use of hormonal preparations to induce the cow to superovulate, i.e., to simultaneously release up to twenty ova from its ovaries, whereupon the cow is artificially inseminated. After six days the fertilized embryos are removed and transplanted into "surrogate" mothers using nonsurgical embryo transfer techniques which already routinized and performed by farmers in developed countries. These techniques make it possible to greatly increase the number of elite dairy cows that can be reproduced.

Embryo transfer is leading to other services. Until recently, the embryos had to be transplanted into the surrogate mother within one or two days, but freezing techniques have improved sufficiently to provide a thirty percent survival rate and is becoming commercially viable. A U.S. company, Genetic Engineering, Inc., has developed a technique for sexing embryos before implantation (Genetic Engineering, Inc. 1982). This allows the dairy farmer to select females and the cattlemen to select males saving the cost of bringing an unwanted embryo to term. It is also possible to split or twin fertilized ova (at this point up to sixteen identical clones can be produced). Because of the freezing techniques it is possible to raise an adult cow, measure its milk production or weight gain, and if production is satisfactory, the elite cow's identical twins can be thawed out and implanted in a surrogate mother.

For TWCs these new animal reproduction techniques offer increased flexibility and opportunities. For example, it is possible to move hundreds of embryos from elite parents in a suitcase sized freezer to any location. The embryos are not subject to quarantine and, of course, are not as large, unwieldy, or expensive to transport as one full-grown cow. As an added bonus, the surrogate mother provides environmental immunities to the young calf, thus drastically reducing mortality rates for cattle imports. The speed with which a Third World cattle herd could be upgraded is greatly increased and purchases of elite germplasm are inexpensive in comparison to adult cows.[12]

Another major obstacle to TW animal husbandry has been the number and seriousness of animal diseases. Biotechnology provides numerous opportunities to attack animal diseases (Table 9 lists disease vaccines under development and some market information). Obviously vaccines could provide important economic benefits. But, as in the case of plant biotechnology, the animal diseases first tackled will be those that are most profitable--not those endemic to the TW. The reason that animal vaccines are so early on the market is a function of two variables. The first variable is that biotechnology expertise was developed in medical schools and biology departments that were doing research on human vaccines. Though the research concerned human vaccines, much of the knowledge easily adapted to animals. The second variable is that animal health products, though similar to human health products technically, require a far shorter testing period and receive rapid market approvals. Therefore, many companies have emphasized animal health products.

For TWCs the single most commercially important vaccine is the foot and mouth disease (FMD) vaccine being developed separately by Genentech and Molecular Genetics (Genentech 1982; Molecular Genetics 1982). FMD is a virulent and economically devastating bacterial disease that infects cloven-hooved animals. The costs of FMD eradication efforts are huge. The elimination of an FMD outbreak in England in 1967-68 cost in excess of $200 million and a similar Canadian outbreak in 1952 was estimated to have cost $1 billion (Blackwell 1980:1019). The high costs of controlling FMD oblige uninfected countries to embargo meat shipments from infected regions such as Argentina, Brazil and most of Africa to the USA and Japan.

The market for a safe, effective, and easy-to-handle FMD vaccine is huge. For example, Argentina imports 200,000,000 doses per year of the attenuated virus vaccine from Burroughs-Wellcome of the United Kingdom (Allende 1984). The vaccine must be administered every three months and, in certain cases, has actually caused FMD outbreaks (Blackwell 1980). The genetically engineered vaccine cannot cause disease outbreaks and should be more effective. A number of companies in addition to Genentech, Molecular Genetics and Burroughs-Wellcome are pursuing a FMD vaccine, though none has yet developed an entirely effective one.

The impact of a totally effective FMD vaccine could be an enormous increase in meat exports by TWCs to the developed countries because the barriers to meat entry into FMD-free countries could be dropped. The increased exports could easily increase the value of grazing land and perhaps cause a shift from food cultivation to animal grazing. Increased meat exports for the tables of the middle-class in the U.S., Europe, and Japan at the expense of the TW poor certainly is a possibility and, perhaps, even a likelihood. Each of the vaccines listed in Table 9 offers the potential of increasing efficiency and productivity in animal husbandry and just as surely offers the possibility of shifting relative factor prices against poor farmers and consumers in TWCs, perhaps increasing relative or even absolute poverty.

Genetic engineering has made it possible to produce bovine, porcine, and chicken growth hormones and bovine interferon. Bovine growth hormone has been shown to increase a cow's milk productivity by between 10-20 percent (Peel et al. 1981). Similar results have been achieved with chicken growth hormone in speeding the growth of broilers (Boone et al. 1983). However, the actual utilization of these growth hormones is blocked by the lack of an adequate delivery system--the hormones are metabolized in the digestive tract when taken orally. Bovine interferon is being tested for prevention of shipping fever, a disease that results in severe weight loss in up to 30 percent of cattle housed in feed lots (Wall Street Journal 1983:36). The increasing number of animal agriculture inputs will make animal production more efficient for those able to afford these inputs. The range of impacts of biotechnology on animal husbandry is truly profound. The changes will provide opportunities for drastically increasing productivity and international trade. Whether this will improve the living standards of peasants and TW consumers depends upon the steps taken to insure distributive equity.

Industrial Plant Tissue Culture (PTC)

The increasing skills of manipulating plant materials in tissue culture has made it possible to select and reproduce plant cells that produce valuable chemicals *in vitro*.(13) Rapid advances in PTC have made what was formerly only a scientific tool into a commercial innovation. There are already two PTC products available to consumers: shikonin, produced by Mitsui Petrochemical Co. (Tanaka 1983a) and berberine, produced by a German company (Zenk 1984). Increasing numbers of DC research laboratories, both public and corporate, are initiating PTC research and many high value plant-derived products are vulnerable to displacement. The process of substituting industrially produced inputs for agricultural commodities is not new, e.g., the displacement of indigo with aniline dyes. PTC will continue and exacerbate this historical trend. TW agricultural planners must understand the reasons for product displacement so as to be better prepared to counteract the process.

There are a plethora of plant products cultivated for pharmaceuticals, dyes, flavorings, and other specialized high value uses. Typically, these plants can only be cultivated in certain specific geographical and environmental regions. Conversely, locales cultivating the plants may be very dependent upon the income generated from sales of the products. PTC will significantly impact these economies as DC importers increasingly will be able to manufacture these products in fermentation plants (Table 10 presents a list of products currently undergoing PTC experimentation).

PTC has many advantages when compared to conventional agricultural production. The production of plant chemicals in an industrial process allows more complete quality control and product supply would no longer be subject to the vagaries of weather, transportation, season or politics--the production process is more controlled and predictable. Difficulties with farming systems such as the ability to recruit more farmers and secure suitable land are circumvented. Fermenter-based production processes are more flexible thus, if larger product quantities are needed the company need only add another fermenter. Conversely, if a product oversupply exists the fermenter can either be mothballed or transferred to manufacturing other products--a very difficult and expensive switch for a farming system. For many plant products sophisticated, expensive separation systems to extract the desired chemicals from the economically useless parts of the plant are required. For example, the active ingredients of the opium poppy must be extracted from cell mass of the poppy buds at considerable expense, whereas with PTC only cells producing the active ingredients are cultured. A PTC factory can work continuously thereby eliminating the need for sizing the plant for peakload. Whereas the machines for conventional agricultural production are in use only during the harvest season.

The primary disadvantage of PTC remains the high costs of production. The point at which PTC becomes a viable alternative to agriculture has been estimated to be at approximately $600 per kilogram (Leonard 1983; Tudge 1984). However, it should be noted that increasing research and production experience will allow these production costs to be brought down significantly. The lack of experience in handling large-scale fermentation operations is also a handicap to industrial production, but this is being overcome by scale-up research and "hands on" experience.

As indicated earlier, the impact of PTC will not be immediate but cumulative as the TW producers experience product market stagnation and eventual erosion. A vivid example of this was the destruction of the Indian indigo industry in the pre-World War I period by the German synthetic indigo dye industry built by companies such as BASF and Hoechst. When the synthetic was first marketed in 1897 there were 574,000 hectares under indigo cultivation in India, by 1911 the land under cultivation had declined to 86,600 hectares, and by 1920 the industry had nearly disappeared (Martin-Leake 1975:368). The Indian regions formerly most dependent on indigo cultivation still have not entirely recovered from the effects of this technological innovation. Similar displacements occurred in the post-war period as nylon rope made by Dupont drove jute (Bangladesh) and hennequin (Yucatan, Mexico) from the world rope market. Another well documented case of displacement by scientific innovation is the demise of the Mexican steroid industry in the 1970s (Gereffi 1978). PTC is so important because it can be applied to any plant, whereas synthetic techniques are limited by the technical difficulty of synthesizing many plant products.

Many products that could be displaced by PTC are the monopoly or near-monopoly of a select few countries. These countries must prepare for the dissolution of these monopolies by pricing products in such a way as to either extract maximum profits to be invested in other industries or in rationalizing production so as to be more competitive. To merely remain idle or blissfully unaware of the biotechnology's threats is not a viable alternative. The result of inaction will be the destruction of an export industry with no plans prepared to alleviate the plight of the farmers and workers dependent upon that industry.

Genetic Engineering and Industrially Produced Agricultural Products

This section discusses a heterogeneous number of other biotechnology applications which will profoundly impact agricultural systems. The majority of these techniques are targeted for DC agriculture. Nonetheless, areas such as improved nitrogen fixation are also receiving attention in TW research institutes. Other research such as single cell protein production is confined to DCs and their MNCs. For purposes of clarity the following discussion has been divided between industrial processes using genetically engineered microorganisms and genetically engineered inputs to agriculture such as microorganisms and microbial pesticides.

Industrial Microbiology

The engineering of a microorganism's metabolic pathways makes it possible to efficiently convert low value feedstocks into higher value products such as amino acids, proteins, and specialty chemicals. In certain cases the products of these altered microorganisms will efficiently compete with agricultural production. Much research money is being invested in developing microorganisms capable of transforming agricultural wastes consisting largely of cellulose and lignin into higher value products. However, researchers have yet to do it economically. Table 9 indicates there are a number of applications currently being investigated and will undoubtedly be many more as increasing numbers of MNC food processing giants enter the industry.

The microbial production of SCP has received much attention from large petroleum and petrochemical companies due to protein's relatively high value. For two years, Imperial Chemical Industries has produced SCP animal feed but the facility has yet to become competitive with soybean protein. The ICI process feeds yeast on methanol and requires an approximately equivalent amount of fossil fuel energy as soybean production, while using only one-tenth the labor, however capital investment is very high (Yanchinski 1981). If increasingly efficient yeast strains and process engineering are developed the SCP process may become cost-effective. For oil exporting countries the production of SCP may make economic sense even earlier because of the "free" natural gas. The successful entry of OPEC countries into the world protein markets would certainly disrupt the agricultural economies of countries that export cattle protein feeds (soybean cake - U.S., Argentina, and Brazil and peanut cake - Senegal and other West African countries). However, SCP has not yet had even a modest economic success.

On the other hand, the fermentation of the amino acid, lysine as a cattle feed supplement has grown immensely. The two major world producers, Ajinomoto and Kyowa Hakko, have recently constructed new amino acid production facilities in the U.S. and both are actively using genetic engineering to develop more efficient microorganisms (Yugari 1984; Samejima 1984). Lysine is an example of the contradictory impacts biotechnology could have. Genetic engineering of microorganisms could make lysine production less expensive, but genetic engineering could develop corn plants that produce sufficient lysine so as to eliminate the need to add lysine to cattle feed. Research, investment, and success in either option will impact the structure of agriculture differently.

Genetically improved microorganisms could provide Brazil's ethanol program with much more efficient production processes. This may be a mixed blessing because the current ethanol project has already contributed to a redistribution of income and land away from peasants and workers and toward the sugar barons (Vellutini 1984). Therefore, making the project more efficient may only encourage the spread of sugarcane farming compounding rural poverty. French researchers are also undertaking to develop microbial techniques to transform inexpensive oils such as corn oil into more valuable oils such as that of cocoa (Canteley and Sargeant 1981:331). In this case many LDC plant oil exporters could be seriously affected by competition from DC companies in the international food oils market. Examples of other techniques under development include one Japanese company's plan to develop bioreactors on board vegetable oil tankers (Tanaka 1983b). These tankers would process the food oil even while enroute to Japan decreasing the necessity of investments in food oil processing plants in DCs and shortening product turnover time.

Microbes and Microbial Pesticides as Agricultural Inputs

The use of microbes in agriculture has received increased attention due to increased emphasis on the use of more environmentally benign agricultural inputs. The variety of beneficial agricultural microbes ranges from insecticide and fungicide producing to nitrogen fixing and frost preventive bacteria. Within this broad range there are many applications that could quickly be adapted to TW conditions and in many cases would require very few imports.

Perhaps the best known insecticidal microbe is *Bacillus thuringiensis*, a virulent antagonist of many insects. In combination with integrated pest management techniques the use of microbial insecticides can significantly reduce pesticide costs (Orrego 1981:67-75). Already UNDP/FAO is funding projects to use *Bacillus* to control olive pests in Greece and alfalfa pests in Argentina (Orrego 1981:68). Similarly, the fungus, *Trichoderma harzianum*, is being used to control other fungi (Orrego 1981:77). These microbial pesticides are being sold in the DCs by companies such as Upjohn. However, in many cases, crude but effective methods can be developed to produce these pesticides in Third World environments at very low cost.

Another important agricultural role for microbes is in the fixing of nitrogen from the atmosphere. This can occur in three ways: through bacteria living in symbiosis with legumes, free-living microbes in the soil, or blue green algae. The most radical claims of certain biotechnologists has been that they will engineer grain plants able to fix their own nitrogen. The technical difficulties of genetically engineering symbiotic nitrogen fixation are enormous, e.g., there are at least seventeen genes involved with symbiotic nitrogen fixation. Questions have also been raised as to whether yield losses due to nitrogen fixation energy demands would be economically prohibitive (Anderson 1980:35). A corollary question is whether photosynthesis in plants can be made efficient enough to compensate for the energy used in nitrogen fixation (Anderson 1980:38). In fact, engineering corn to fix nitrogen could lead to yields at least 10 percent lower than those currently achieved (Chemical Week 1980:28). Plants and bacteria engineered to symbiotically produce nitrogen economically is probably far in the future and even genetically "improved" free living soil nitrogen fixers probably may not be successful in competing with the naturally occurring soil bacteria or natural gas-derived fertilizer.

The most promising research area for reducing fertilizer consumption in the next ten years is the development of farming systems using blue-green algae and Azolla (Jagannathan et al. 1978:20). The Azolla ferns provide energy and living sites for the algae and the algae produce nitrates which the Azolla absorbs. Rice paddies fertilized with composted nitrogen-rich Azolla report yield increases of 12-14 percent higher than yields in control rice plots. IRRI has had considerable success in spreading the usage of Azolla to countries in noncommunist Asia--Azolla was first used in North Vietnam and China. Nevertheless, though research is forging ahead and a number of research institutions are committing research funds to biological nitrogen fixation, success in fields other than Azolla usage is probably relatively remote.

The reason for great emphasis on biological nitrogen fixation research in TW environments is obvious--foreign exchange savings. Whether, with the exception of the Azolla research, BNF is a well placed investment is certainly open to question. For example, J. Eugene Fox (1984), president of ARCO Plant Research Institute, believes any viable applications of BNF are at least five to ten years away. The problems with BNF include: 1) normal soil conditions may not provide free-living nitrogen fixers with the required energy sources, 2) the nitrogen that is produced will not be directly absorbed by the plant, thereby rendering the process relatively inefficient, and 3) ammonia may be overproduced rendering the soil acidic. BNF, at first, appears to be an ideal strategy--fertilizer can be produced by farmers at very low cost. However, if the BNF research does not successfully come to fruition, TWCs will have squandered much of their research resources on a gamble that has already been abandoned after major investments by companies such as Allied Corporation.

Summation

This section has briefly surveyed the myriad possibilities that the new biotechnologies are providing for agriculture. In a number of specific instances the political economic implications of the commercial success of these developments were highlighted. It is obvious is that each of these techniques has contradictory implications. The benefits of biotechnical change will be captured by those social groups most able to shape research agenda and demand their share of the benefits. If the poor and oppressed cannot make their desires heard, they will most certainly not reap the benefits of this new productive force. This is especially true in a global economy in which biotechnology is increasingly becoming a science controlled by a corporate research agenda based upon profit maximization and not by the needs of the TW poor.

TWCs must become actively involved in biotechnology research. The biorevolution will involve all areas of agriculture regardless of whether a single country opts to invest in biotechnology. The uniqueness of biotechnology is that there are many levels of entry and economies of scale are not entirely operative. Useful products can be generated at very low capital intensity, this is a knowledge-intensive industry and its tools can be directed at unique national problems. However, it must be recognized that biotechnology is not a panacea nor will research yield rewards overnight.

Third World Countries' Responses to Biorevolution

The biorevolution offers many opportunities to TWCs to secure real economic gains. However, securing these gains will require more than simply lavishing money and equipment on scientists and hoping for success. Fundamental to long-term success is a program of elementary and secondary education dedicated to bringing hands-on scientific experience to a nation's students. TWCs will be required to inventory their national resources and prepare a long-term biotechnology plan complete with targets and realistic goals. Applied research must be directed in such a way as to maximize its relevance to the needs of the country. This emphasis on applied research must be reinforced by analysis of what is technically and economically feasible.

There is no single correct strategy. For example, India with its large research budget and pool of trained manpower will necessarily have a different approach from that of, say, Zimbabwe. Yet, even the smallest and poorest countries can participate in the biorevolution through regional and international networks. Participation need not be in the most sophisticated basic research, but rather should match national skills and research expertise with problems that can be tackled. The greatest mistake would be to attempt to mimic the research agendas of the DCs.

Biotechnology Institution Building

The difficulty of establishing a biotechnology industry in TWCs is obvious. It is useful to briefly list some obstacles to establishing an effective national bioindustry capable of providing products to enhance development. The first principle is that the biotechnology industry is more knowledge-intensive than capital-intensive, but biotechnology is not a free good. As mentioned earlier, a U.S.-style "high tech" biotechnology company would require at least well-trained 25 Ph.D.s and approximately $10-12 million in initial investment capital. The scale-up of R&D to the industrial level would cost much more. Yet, even Eli Lilly's rDNA insulin plants cost only $40 million each (Kramer 1982:1). A monoclonal antibody endeavor would probably cost from $3.5 to 4 million over three years (Treble 1982). In fact, few of the biotechnology start-up companies in the U.S. have invested more than $200 million dollars since their founding so the costs are still relatively low. DC-level tissue culture laboratories for plant improvement capable of having a number of ongoing projects can be established for $100,000 to $300,000 (Zapata 1984).

These costs may seem high, yet when compared to the costs of building luxury car assembly plants or importation of weapons, the costs of scientific research are not unreasonable. The most sophisticated equipment need not be purchased immediately, but rather a well-planned purchasing schedule could be developed to bring new equipment into service gradually. This allows the equipment to be absorbed and brought into service in a deliberate, rational manner.(14) This also would encourage scientists to become resourceful and innovative in coping with shortages.

The greatest obstacle to LDC involvement in biotechnology is not lack of investment capital, but rather a lack of trained personnel. The decades of "brain drain" have resulted in the emigration of many Third World scientists.(15) This drain has been accompanied by lack of emphasis upon and opportunities in the TW to do basic or applied biological research. Many of the TWCs' most able molecular and cell biologists, virologists, and immunologists, after post-graduate training remained in the DCs. Another complication is the fact that many TWC scientists have financial linkages to DC companies.

The lack of trained scientists is not the only personnel deficiency experienced in many TWCs. There is also a shortage of trained technicians capable of maintaining and repairing sophisticated scientific machinery. Technicians are a vital component not only for laboratory work, but also for the process of moving to full-scale production. Technicians as a group are often neglected because of their comparatively low prestige and pay, yet they are absolutely vital to a successful biotechnology industry. Thus far, only a few countries, e.g., Mexico, Brazil, India, Cuba, and China have the critical mass of scientists and technicians necessary to launch a viable large-scale biotechnology effort.

There are other LDC disadvantages that can be characterized as infrastructural in character. David Baltimore (1982), Nobel Laureate, professor at MIT, and part owner of Collaborative Research, has pointed out the critical need that biotechnology R&D facilities have for steady, dependable public utilities such as electricity and water. For example, a prolonged electricity outage could result in the loss of months of work. Transportation services are also important, because certain enzymes are very unstable and must be delivered in a frozen state within 48 hours of shipping or they deteriorate and become useless (Baltimore 1982:34). Biotechnology laboratories also have sophisticated imported machinery that is difficult to service and might experience long downtimes while waiting for repair or service originating in developed countries. The entire problem of inadequate infrastructural development may be even further reinforced during periods of economic or political uncertainty when the immigration and customs service can almost completely break down.

Another blockage in creating an effective biotechnology industry may be characterized as a lack of political will and resolve. An investment in biotechnology is not a one-time investment, but rather requires constant and growing investment as projects come to fruition. The prospects for immediate riches such as are realized in the U.S. when the stock is sold to the public are not possible in TWCs. False expectations of the ease of success sometimes fostered by the scientists themselves will rebound to the detriment of creating a viable biotechnology industry.

The final important obstacle to success in biotechnology is the choice of appropriate research targets. The usual scenario is the TW government to respond to a perceived need for a biotechnology industry by requesting university scientists to formulate a biotechnology program. This program is then funded by the government with little further analysis. The professors then allocate the money among themselves, return to their laboratories, and continue their ongoing research. Years pass, very little emerges from the laboratories, and government interest and funding wanes. Eventually, the country finds that it is hopelessly behind in the technology and large sums have been used in a manner that will provide no return. Only after appropriate business-like analysis of the financial costs and benefits should a project be financed. The criteria for financing must be based on reasonable opportunities for economically viable success, simply accepting the claims of scientists is <u>not</u> sufficient criteria for fund allocation.

National Biotechnology Programs

A number of countries have launched national biotechnology programs including: Cuba, China, Brazil, Argentina, Thailand, India, Algeria, Korea, the Philippines, and many more are making investments in this area. This section will examine the undertakings of two very different countries, India and Cuba, outlining the strengths and weaknesses of their respective efforts. The programs of other countries are also briefly discussed. Linkages between institutions in the DCs and TWCs are described and their benefits and costs are explored. It is argued that biotechnology is a broad field in which the resourcefulness and flexibility of TW scientists will provide ample opportunities to develop research programs uniquely suited to particular national needs.

India

India will undoubtedly have some success in its biotechnology effort due to its large industrial base and extensive cadre of educated scientists. The Indian biotechnology effort received top-level support from the late Prime Minister, Indira Gandhi (1982), and is able to tap the expertise of top Indian emigre scientists.[16] However, an important (and unpredictable) variable affecting the success of the Indian effort will be the degree of commitment that the important Indian private sector will assign to biotechnology.[17] With the support that biotechnology is receiving at the political level India will develop a viable program.

The late Indira Gandhi established a National Biotechnology Board (NBB) to organize India's national effort. The NBB (1983) has developed its "Long Term Plan in Biotechnology for India" that formulates specific proposals meant to ensure India's participation in biotechnology. The NBB will encourage and facilitate interdisciplinary research and build the infrastructure necessary to support research. For example, the Indian government has undertaken to import and supply necessary enzymes and biochemicals and is setting up production facilities for the most important of these (NBB 1983:30). The government is also giving high priority to the import of needed equipment. In the personnel area, the plan calls for the training of 50-100 "biotechnologists" annually. On the other hand, no mention is made of training technicians to repair equipment and assist in other activities crucial to laboratory success.

India is rich enough in universities and research institutes that it can do any but the most state-of-the-art research. India's large number of researchers, stable foreign exchange situation, and excellent universities permit infrastructure building which most countries could not afford or support. The Indian government is developing a large-scale program that addresses all aspects of creating a biotechnology industry. The success of the program will significantly contribute to Indian agricultural and industrial productivity. Another major contribution to the Indian biotechnology effort was the decision to locate one center of the International Center for Genetic Engineering and Biotechnology (ICGEB) in India.

Cuba

In contrast to India, Cuba has a much smaller industrial and research base. However, this has not precluded Cuba from making an important investment in biotechnology. The Cuban R&D goals are strongly influenced by the concrete development and needs of the economy including: the commitment by the Cuban state to improve medical care, the importance of agriculture (sugar and tobacco) to the economy, the political commitment to raising animal protein consumption in Cuban diets, the desire to be an exporter of biomedical products, and strong research capabilities in the agricultural and medical sciences. However, Cuba does not aim to be a scientific leader in world biotechnology. Rather, the Cubans wish to take advantage of the results of research conducted overseas by remaining somewhat behind the cutting edge of DC science, yet in a position to exploit commercial aspects of scientific developments.

Cuba launched a biomedical genetic engineering laboratory with its first project being to produce interferon using the Cantel process. Laboratories are also examining the possibility of using rDNA to produce alpha interferon. In pursuit of the interferon project, Cuba has held an international interferon conference in Havana and launched a journal entitled <u>Interferon e</u>

Biotecnologia. The reasons for undertaking the interferon project are: 1) to be used as a model system to learn rDNA techniques; 2) for its immediate medicinal usage (Ubell 1983:344); 3) the personal interest that Fidel Castro has in the project (Anonymous source 1984); and 4) as a demonstration of Cuba's technical expertise. Other major projects underway are the use of tissue culture to improve sugarcane and animal vaccine production. Cuba has also had success in bovine embryo transfer (Paiges 1984). Finally, Cuban scientists claim to have successfully extracted lysine from yeast and already introduced the method into Cuban industry (Ubell 1983:746).

Cuba is launching an expensive product-focused drive to introduce biotechnology into the economy. Eric Holtzman, a Columbia University professor of cell biology, states: "They've aimed very carefully to develop a scientific enterprise which is not intended to ape world class research" (quoted in Ubell 1982:745). The Cubans have chosen targets that can benefit the ordinary Cuban. The reason for this targeting according to Cuban scientists is that relative poverty and immediate problems prevent investments having no medium-term payoff. This, of course, implies that the Cubans will remain consumers rather than producers of basic research.

Under the very adverse situation which limits Cuban access to U.S. universities and laboratories, Cubans have been very resourceful in securing access to information. Cuban scientists have trained in Europe and the USSR. Cuba also actively encourages foreign scientists to conduct scholarly visits, e.g. Marc Van Montagu, one of the world's foremost plant scientists, recently visited Cuba (Osa 1984:4). Technicians are sent for training to Japan and elsewhere to learn to repair and maintain purchased equipment (Ubell 1983: 344). Though the Cubans are now producing some equipment and enzymes, the more sophisticated items are still imported. To increase access to foreign information sources the Cubans are to be linked to the Soviet on-line data retrieval network (Ubell 1983).

The Cubans, though having a much smaller population and industrial base than India, are making a determined effort to participate in the biorevolution. As part of this strategy, they are taking advantage of linkages and services offered by international and regional organizations such as the fledgling Latin American Biotechnology Network. The success Cuba has had in building a significant advanced biotechnology research establishment clearly demonstrates that political commitment and desire can overcome many obstacles.

There are even simpler efforts than those discussed thus far that can be undertaken such as clonal propagation of certain agriculturally important species. For example, in Vietnam family-size potato tissue culture facilities have been established. These laboratories reproduce and distribute to farmers elite potato varieties such as those developed by the International Potato Center (CIP) in Peru. A single facility can produce 100,000 clones per month, rapidly speeding the diffusion of new varieties (Uyen 1984:5). The Vietnamese example illustrates that biotechnology can be adapted to meet many different goals. Other countries as varied as Nicaragua and the Philippines are developing low-cost techniques for microbial pesticide production. In many ways biotechnology success is only limited by the dedication and imagination of TW scientists.

Linkages Between Third World Institutions and Biotechnology Startups

The traditional routes for TW institutions, private and public, to secure technology has been either to contract with large MNCs to provide licenses, set up joint ventures with MNCs, or to utilize the expertise located in DC research universities. Thus, agricultural pesticides, farm machinery, and fertilizer were imported or produced under license while plant breeding, soil science, and animal science knowledge was secured from universities in DCs or for certain crops at the International Agricultural Research Centers (IARCs). The changing university-industry relationships in the DCs are threatening to disrupt this traditional pattern as both universities and their professors are now forming far closer links with industry. For LDCs these new arrangements present a number of problems. The foremost is that LDCs may not have the financial resources to purchase this recently privatized research.

A TWC must be very careful when it enters the market for technology because corporate sellers will quite naturally attempt to extract the highest price. Previously, the DC universities were locations where useful knowledge could be secured at far lower cost or even gratis. As was illustrated earlier this has changed with the commercialization of biotechnology. In many cases the university no longer is merely a disinterested institution producing knowledge for the public benefit, rather the university and its professors have become much more conscious of the possible value of their research.

These changes have made it important for TWCs to remember when dealing with professors in DC universities that the professor's survival is dependent upon an ability to attract research money. In biotechnology this money is increasingly being furnished by industry. A country wishing to secure research from this professor or link with him in a "twinning" arrangement, must be aware of how the professor's economic interests may conflict with other goals. For example, in the growth of the U.S. biotechnology industry useful university inventions have been transferred to companies with the collusion of academic personnel (Kenney forthcoming). The dangers can be illustrated in the following hypothetical case. If a joint research project between a TW scientist and a U.S. scientist leads to a superior method of cloning coconut palms, it might be possible for the U.S. professor patent the invention secretly. The TW scientist could possibly get the patent disallowed in his country, but any products using the newly patented process would still be forbidden from entering other countries where the patent was valid. Further, the DC professor could sell the products of the work in all other countries. Thus, the question of cooperation is no longer a simple decision on scientific grounds and academic trust--<u>biotechnology is business</u>.

Other changes in university-industry relationships are underway. Nearly all the good university biotechnology laboratories are being provided with major corporate funding ($100,000 or more per annum). In some cases, the companies have patent rights, in others, the companies merely wish to "observe" the research progress. It can be assumed that if a TW researcher or student brings an interesting plant variety for research, it will end up in the collection of that company. Knowledge and research materials now have value and accordingly attention must be paid to their transfer.

The small NBFs, however, do provide interesting opportunities for TWCs to secure specialized expertise. Contrary to the large MNCs that have very strong cash flows and rarely license anything but older, less profitable technologies, the NBFs are willing to sell state-of-the-art technology. There are a variety of reasons for this willingness, but first and foremost, is the fact that <u>these companies need money</u>. Another aspect is that the NBFs believe that LDCs will not compete with them in U.S. markets. Whereas if they sell technology to an MNC they are providing knowledge to a real or potential competitor. Finally, the NBF's employees are former academics and some of these individuals do have genuine concerns about the TWCs. Therefore, it may be possible to purchase specific items or knowledge at relatively low cost.

A number of TW governments and companies have already signed contracts with U.S. NBFs (Table 11). If a TW company or country knows exactly what it needs and is able to bargain effectively with the NBFs, then a mutually convenient arrangement could be established. The types of services these companies could render include: the training of TW personnel in scientific techniques, contract research, joint ventures, and marketing arrangements. The weakness of many of these linkages is that TW scientists would not learn the scientific techniques used to create the product. Another possibility is to contract the company to provide a turnkey biotechnology facility. However, this assumes that trained personnel are available to use, manage, and maintain the facility. This section's purpose has not been to recommend such linkages nor to exhaust the possible types of arrangements. It is important to indicate possible strategies for securing information access that are available due to the new relationships in the DC scientific communities.

International and Regional Networks

The promise of biotechnology for development has led to a flurry of activity on the part of development organizations. A major aspect of these efforts has been to develop information transfer networks. Networking will be especially important because it provides a way in which critical masses of researchers can be coalesced even though the researchers are in different locations. This is also important because many TWCs suffer from similar problems and can learn from the knowledge developed in other countries. The first UN agency to recognize the importance of the impending revolution in biotechnology was UNESCO which began to organize networks of researchers around its MIRCEN (Microbiological Resources Centres). The MIRCENs provide nodes through which information is transferred and contacts made. UNESCO also provides small grants and arranges training courses for scientists from TWCs.

The best known international effort in biotechnology is the newly approved International Center for Genetic Engineering and Biotechnology (ICGEB) founded under the auspices of UNIDO. After a long acrimonious debate the decision was made to split ICGEB with one site in Trieste, Italy and one site in Delhi, India. The founding of ICGEB leads to questions regarding its research agenda. Given the nature of biotechnology there are an almost infinitely large number of projects that could be undertaken. Should ICGEB's aim be teaching, research success, or real products? It will be difficult to be successful at any one and they are not necessarily complementary. ICGEB is modeled upon the successes of the IRRI and CIMMYT, but both IRRI and CIMMYT had specific crops and concrete goals, i.e., to raise TWC grain yields. ICGEB does not have such a strong specific goal and therefore may suffer from a lack of clear targeting culminating in a diffused and ultimately not very forceful effort.

If ICGEB's agenda is to be agricultural in orientation, then very different scientific skills will be required from those needed for an industrial fermentation-oriented research facility. Crop selection would also become a political question and it is not clear that ICGEB would be the correct location for crop biotechnology research. An item of concern is that in case of breakthroughs in producing new plant varieties would ICGEB have an outreach or extension program capable of moving the new plants to the field?

Also, problematic is the dual campus aspect of ICGEB--securing cooperation between the campuses may be difficult.

There are a number of other United Nations organizations that have made investments in the biotechnology, e.g., UNESCO, FAO, WHO, ILO, UNDP and UNU. This widespread involvement is indicative of the breadth of the coming biorevolution and the difficulty of tackling its implications by merely discussing, say the farming system. For example, if World Health Organization research produced vaccines or pesticides effective against the vectors of yellow fever, malaria, and trypanosomiasis, then African agriculture would be immeasurably changed. There are good reasons for all of these organizations to be involved.

International Agriculture Research Center (IARC)

The IARCs have been important institutions in developing and transferring the results of applied plant breeding to TW agriculture. The biorevolution will provide new tools to agricultural scientists with which to produce higher yielding and stress tolerant varieties. To successfully deploy the new techniques will require scientists with skills in areas not traditionally associated with agricultural science such as molecular and cellular biology, immunology, oncology, and virology. The influx of these scientists will also require the IARCs to do research that is more basic than they have traditionally undertaken.

The leading IARC in exploring the potential of biotechnology for TW agriculture has been IRRI. In April 1984 IRRI hosted the Inter-Center Seminar on IARCs and Biotechnology and a report was issued making a number of recommendations regarding potential technical developments of possible interest and use to IARCs. The major recommendations of the report grouped under "Intensification of Cooperative Research" included:

1) Increased twinning of IARCs and advanced laboratories in DCs.
2) Trilateral linkages between an IARC, a developing country laboratory, and one in a developed country.
3) Encouragement of increased scientist-to-scientist interaction between IARC scientists and those in biotechnology laboratories.
4) The organizing of cooperative networks of scientists in numerous countries in fields such as tissue culture.
5) Exchange of scientists especially by encouraging visiting scientists to fill gaps in internal competence of IARCs (IRRI 1984:27).

Recommendations under the heading "Institutional Arrangements" were:

1) To organize an intercenter seminar on biotechnology every three years.
2) For each center to organize a biotechnology working group to be chaired by the director general of the institute.
3) To include an outstanding cell or molecular biologist as a member of the IARC's Technical Advisory Committee.
4) To organize training courses in biotechnology for TWCs (IRRI 1984:28).

Very obviously, the IARCs will be crucial in transferring the biotechnological breakthroughs in their designated crops to TWCs. This role will require coordination with ICGEB to ensure that duplication of effort is minimized. And, in fact, the IARCs are probably better suited to be lead research institutes due to their already very strong crop-specific outreach networks. Operating through the IARCs in diffusing biotechnical knowledge may lessen the need for ICGEB to duplicate research already underway in agriculture. The IARCs fully expect to increasingly use biotechnology to reinforce their conventional capabilities (Swaminathan 1982). However, the division of labor between the IARCs and ICGEB has not yet been settled nor have the IARCs yet developed the requisite biotechnology expertise.

Regional Networks

Another method by which TWCs are attempting to overcome their late start and lack of a critical mass of researchers is to form regional networks. The UNDP and UNESCO have provided monies for the countries of Argentina, Brazil, Chile, Costa Rica, Cuba, Mexico, and Venezuela to organize a Latin American Biotechnology Network. This plan includes the eventual linking of the countries through a computer network (Krauskopf 1984:2). There are also plans to contract with Latin American laboratories to produce biological research materials such as restriction enzymes, oligonucleotides, etc. The production of these materials not only provides important hands-on experience, but also loosens dependency on DCs and demands for hard currency (Allende 1984). This network would be the first TW biotechnology network and will provide opportunities to strengthen biotechnology in Latin America. The Latin American network is being built on the experience amassed from a Latin American biology training network and provides an opportunity for developing biotechnical knowledge through the collective effort of TWCs.

International Biotechnology Efforts and Agriculture--Some Thoughts

Perhaps, for the first time in history TWCs are demanding a role in and a share of the benefits of a new technology before rather than after it has been deployed. This sentiment was best expressed by the late Indira Gandhi (1982) who quoted Cecil Powell in a recent issue of *Science*: "If we left the development of science in the world to the free play of economic factors alone, there would inevitably result a most undesirable concentration of science and scientists in too few centres, those rich in science becoming even richer, and those poor relatively poorer." To capture the promise of biotechnology will require a depth of commitment, honesty, and realism that has sometimes been lacking among TW science policy makers. But, in contrast, to technologies such as nuclear power, satellites, fiber optics, and robotization, biotechnology offers areas of potentially lucrative research to all but the smallest countries and these countries can participate in regional biotechnology networks.

Biotechnology will have incalculable economic impacts over the next twenty years and have far-reaching social repercussions. Agriculture as much or more than any other human activity will be transformed by biorevolution. Biotechniques such as tissue culture can be practiced with only small capital investments, yet can yield very real benefits to farmers. Plants that can expect little research attention from developed country scientists such as tropical hardwoods, could provide handsome economic returns to a country willing to invest in research. Similarly, the development and use of microbial pesticides could contribute not only to alleviating the costs of imported pesticides, but also would be environmentally benign. There are so many technologies and so many possibilities in agriculture that choices of research goals will need to be made on the basis of rational analysis and not on speculative promises.

The increasing role of private industry in biotechnology is beginning to control and reroute the formerly free flow of information as professors become increasingly involved in ownership of biotechnology companies. As university administrators and professors in DCs become increasingly linked to private industry it may become increasingly difficult for TWCs to secure unbiased advice from university scientists. The phenomenon of patenting and plant variety protection will also serve to block the ability of TWCs to access information produced in the DCs. It is paradoxical that in this age of information and networking that it is information and knowledge that will be increasingly withheld from the poorer countries--even as these countries supply the genetic information in the form of germplasm to developed country plant breeders. However, in many TWCs patent law is not well enforced and the techniques of biotechnology once mastered are relatively simple to repeat. Thus, for countries not encumbered with the patenting system many of these products may be comparatively easy to produce.

Private capital sees sectors of TW agriculture as markets for the biotechnology products it is developing such as pesticides and seeds. However, MNCs will only supply these products to TW farmers with sufficient currency to allow the company to make a profit. The product developed and the recipient of the product will be chosen without reference to any goal but the maximization of profit. Private industry because of its duty to its stockholders must necessarily respond to the goal of securing profit for its owners regardless of its impact on society. However, for TWCs biotechnology is too important to allow narrow self-interest to control its deployment.

Biotechnology--A Simple Technical Appendix

This appendix briefly describes some of the more important techniques that fall under the broad rubric of biotechnology. Bull et al. (1982:21) define biotechnology as "the application of scientific and engineering principles to the processing of materials by biologic agents to provide goods and services." The U.S. Office of Technology Assessment (1981:49) also attempted a definition: "Biotechnology involves the use in industry of living organisms or their components (such as enzymes)." Both definitions are very broad and could be interpreted to include a number of activities such as plant breeding and traditional fermentation engineering which are not usually included in definitions of biotechnology. This document uses the term "biotechnology" only to refer to the new biological or drastically improved biological techniques that have been developed over the last ten years.

Older biological techniques used for production such as plant breeding, fermentation and immobilized enzymes will not be replaced by the new biotechnology. Nevertheless, the new biotechnologies will deepen our ability to use and understand how the traditional biotechnologies operate. Molecular and cellular biology are opening up the black box called the cell and explicating its operations at a molecular level. Thus, the older biotechnologies will be used in combination with the new biotechnologies and this combination will yield new productive innovations.

Fermentation

Fermentation can be defined as the use of cell metabolism to convert inputs into another product(s). Fermentation is a traditional technology on the verge of a new revolution in productivity and importance due to the vital role of fermentation as the process by which genetically engineered organisms will conduct their production. Many traditional fermentation processes such as those that make alcoholic beverages, yogurt, soy sauce, and tofu will be made more efficient by the genetic engineering of microorganisms currently used. Other processes such as the production of single cell protein from agricultural or human wastes will depend on the increasing sophistication of fermentation engineering to make them competitive. The success of biological production facilities and the survival of many genetic engineering technology companies will depend on their mastery of fermentation engineering. As with many of the other technologies discussed fermentation engineering can be undertaken at many levels of sophistication and what is appropriate for one task or environment may be entirely inappropriate for another.

Molecular Biology and Recombinant DNA

DNA's structure was first correctly theorized by James Watson and Francis Crick in 1953. The DNA molecule consists of two strands of base pairs stacked upon each other. The ability of DNA to reproduce is because the four bases two pairs can only pair with their complement. Thus, either DNA strand can unfailingly reproduce its complement and in cell division and this is exactly what occurs. DNA in the form of its genes also contains the program which when translated by RNA orders the amino acids that make proteins. DNA does two major tasks in the cell--it reproduces by splitting and contains in the ordering of the bases the program controlling cellular activities (more detailed discussion can be found in OTA 1981; Sylvester and Klotz 1984; Watson and Tooze 1981).

The 1960s were a period of intense research activity as scientists worked on solving the coding problem, i.e. the translation of the DNA code into amino acids. The solution of this problem in the late 1960s combined with discovery of various enzymes that could both cut and bind DNA molecules provided the possibility of rewriting the genetic program. Simultaneously, other researchers had by the early 1970s perfected techniques for inserting foreign DNA into bacteria.

The single experiment and methodology to which the biorevolution can be traced was done by Stanley Cohen of Stanford University, Herbert Boyer of the University of California, San Francisco, and their research teams. These researchers succeeded in inserting a DNA sequence (gene) into a bacteria which then successfully produced the appropriate protein (Cohen et al. 1973). This success made it apparent that a bacteria could possibly be induced to produce any protein. This was the technical breakthrough upon which the biotechnology industry was built.

The implications of rDNA for agriculture are myriad. As we have already seen animal vaccines can now be produced microbially. For example, scientists have recently spliced a rat growth hormone into a mouse. The results were that the mouse grew to rat size (Marx 1982:1298). This research success raises the possibility of producing larger animals for meat consumption. Similarly, there may be possibilities of using rDNA to move single gene traits from one plant to another.

The initial impacts of rDNA agricultural inputs will not be in plants or animals, but rather by the genetic manipulation of microorganisms that are involved in farming systems. Already scientists are proposing to deliberately release genetically engineered microorganisms into the environment. For example, Steven Lindow of the University of California, Berkeley and Advanced Genetic Sciences, a small company, have developed a genetically engineered bacteria meant to increase plant frost resistance. The genetically engineered bacteria is supposed to displace the destructive ice nucleating bacteria which facilitate ice formation on plants during frosts and thereby prevent frost damage (Advanced Genetic Sciences 1983). The simplicity of microorganisms and advanced level of skills for manipulating microorganisms make them the life forms that will first be altered by genetic engineering.

Monoclonal Antibodies

Monoclonal antibodies (MCAs) are the product of a hybridoma. Hybridomas are formed when an antibody producing cell and a cancer cell are fused. A successful hybridoma acquires high rate of reproduction from the cancer cell and the antibody production capability from the other cell. The hybridoma quickly multiplies and each cell becomes a producer of an identical antibody. Antibodies are commercially important because an antibody can target very specific, unique chemical structures termed antigens. If an antigen can be identified as an indicator of a physical feature such as say, cancer, the antigen's presence in a sample can be identified by using a monoclonal antibody, hence the antibody is a highly specific diagnostic.

In medicine the usage of MCAs is growing very rapidly. Hepatitis, giardia, pregnancy, and cancer test kits have already been marketed and many others are being developed. Veterinary applications of MCAs seem fairly routine and can be expected for diagnosing or treating high value animals such as horses, cows, and pigs. Companies such as DNA Plant Technologies are experimenting with ways of using MCAs to diagnose plant diseases in high value plants such as trees. For example, IRRI is considering MCA use to identify rice viruses indistinguishable with current tools (Hibino 1984). The application of MCAs to agriculture will not be enormous, but it will provide a useful tool for certain unique applications.

Plant Tissue Culture

Tissue culture refers to the ability scientists have developed of sustaining living cellular material in an artificial environment, i.e. *in vitro*. The science of tissue culture is quite old, e.g., PTC was initiated in the 1920s (Sondahl et al. 1984). In the intervening year, not only have tissue culture techniques improved immensely, but so has understanding of plant cell physiology and genetics. In the last ten years researchers have discovered many new and possibly commercial applications for tissue culture.

For the sake of brevity and because the focus of this report is agriculture, animal cell tissue culture is omitted from consideration (though it is critical for tasks such as MCA production). PTC has evolved in two very different directions: First, and most important is the potential for improving the traditional plant breeding process. PTC will impact plant breeding in a number of ways, such as speeding the production of new plants, providing better quality germplasm, i.e. virus-free potatoes, and incorporating more genetic variability into the breeder's programs and possibly in the long-term, eliminating the need for elaborate crossbreeding. The second thrust in PTC is towards biosynthesizing valuable plant phytoproducts *in vitro*.

Tissue culture for plant improvement is not one single technique rather it subsumes a number of techniques with very different levels of sophistication involved in their practice. The simplest technique is the duplication of plants through vegetative propagation. This technique is possible because certain plants such as potatoes, cassava and orchids, among others, can be propagated from microcuttings. *In vitro* propagation increases the speed of reproducing new plants and if properly undertaken can assist in the elimination of plant viral diseases. Vegetative propagation using PTC is a proven technology that can be used for the large-scale reproduction of a number of species.

Embryo rescue is another PTC technique that is receiving increased attention. Embryo rescue was developed to save plant embryos that normally would abort due to sexual incompatability. These embryos contain sexual mixes not normally available to plant breeders and are used to incorporate interesting traits into agronomically important varieties. These techniques are already being used for tomato, cotton, bean, banana, and indica rice varieties. Embryo rescue cannot overcome all types of sexual incompatability and, therefore, its use is limited.

A more powerful technique, anther culture, actually was invented in India and has been effectively exploited in China for producing new rice and wheat varieties (Zapata 1984). Anther culture allows the fixation of desired characteristics much more quickly thereby reducing breeding time significantly (Evans et al. 1983). For example, breeding time for a new barley variety was reduced from twelve to five years through the use of anther culture (Kasha and Reinbergs cited in Evans et al. 1983). Already an International Rice Research Institute anther-cultured cold-tolerant rice variety is being field tested in Korea (Zapata 1984). Anther culture not only quickens the breeding cycle but also facilitates crossing domestic plants and their wild relatives thereby incorporating new material into the gene pool.

Other important techniques include protoplast fusion, a technique that allows the protoplast (cellular material) of two widely differing cells to be completely fused. The result is a cell that contains aspects of both cells and, in an increasing number of instances, a whole plant can be regenerated. So, for example, researchers have produced a "pomato," a plant that has roots resembling a tomato plant and stem and leaves resembling a potato plant. Protoplast fusion is a technique that makes possible a mixing of genetic material from widely differing sources. It also makes for a much more thorough mixing than is possible with conventional sexual means. However, this technique remains at an early stage and should improve greatly as it attracts more research interest.

It is paradoxical that PTC first focused on producing exact clones, but it was soon discovered that the tissue culture process created variation, i.e., not all the clones were identical there was what is now termed somaclonal variation. Initially, somaclonal variation was considered a problem, but later scientists recognized this as a source of possibly useful genetic variability. For example, researchers discovered that certain variants actually had superior disease resistance to their parent plants (Evans et al. 1983:495-496). The causes of somaclonal variation are not yet fully understood even though it is already being used in commercial plant production.

PTC for plant improvement encompasses many techniques some of which can be used in very low budget environments. PTC technology is readily available in the scientific literature and a large aspect of success in PTC research is trial and error. Various parameters such as media, temperature, and other environmental factors must be varied to achieve practical success. Because of the "craft" and labor-intense nature of much PTC it offers great opportunities for success to TW plant scientists.

Industrial Tissue Culture

Certain plants produce rare, high value products which are termed secondary metabolites because they are not absolutely necessary for cellular growth (those necessary plant products are termed "primary metabolites"). Often the secondary metabolites are produced by specific types of cells, e.g. root, bark, flower petals. PTC makes it possible to grow and harvest these secondary metabolite-producing cells *in vitro*. In fact, scientists have succeeded in inducing these cells to biosynthesize up to ten times greater amounts of the desired compound (Yamada 1984). Other ongoing PTC research concerns designing a suitable mass production fermentation process, preferably continuous (Kenney et al. 1984).

Bioinsecticides

The recent controversies regarding the environmental costs of using crop protection chemicals combined with price increases has encouraged university scientists, government officials, and chemical company researchers to investigate the efficacy of naturally produced insecticides and herbicides in a griculture. The biocides can: 1) draw upon natural chemicals that plants produce to ward off predators, 2) use products of a predator's own hormone system to interfere with its normal activities, e.g., the use of an insect sex hormone so as to interfere with that insect's reproduction, and 3) draw upon the increasing number of bacteria and viruses that prey upon plant predators, e.g. *Bacillus thuringiensis* controls upon a number of commercially important insects (for detailed discussion, Orrego 1981).

The principles behind biocide use is that in nature plants and microorganisms are in a constantly evolving competition. Researchers are attempting to use nature's own weapons against agricultural pests. For example, bacteria are used to infect and kill insects infesting a field, i.e., create a disease epidemic in an unwanted group of insects. As a bonus, the bacteria expire when they have no more hosts, thus eliminating the problem experienced with chemical pesticides which tend to linger in the environment. Other plants produce chemicals that discourage plant growth (allelopathic) creating "living" space around themselves. These genetic traits might be very useful in crop plants. The emphasis of this type of research is to harness natural forces to man's needs.

There can be no doubt that the entire field of biocides is only in its infancy and will surely grow during the next decade. In the case of useful bacterial and viruses the research effort need not be highly sophisticated and can be conducted by teams of entomologists and microbiologists. For example, a number of LDCs have developed *Bacillus thuringiensis* preparations for use against their particular insect problem. The entire field of bioinsecticides (and integrated pest management) offers great potential for significantly lowering the costs of pesticide imports while decreasing environmental damage.

Biological Nitrogen Fixation (BNF)

BNF has received much attention in the last ten years because of the enormous costs farmers are incurring in the purchase of nitrogen fertilizer. In the case of nitrogen, the problem is not that there is insufficient nitrogen (80 percent of the atmosphere is nitrogen), but rather its chemical form makes it unavailable for plant use. However, there are strains of bacteria and algae that can convert atmospheric nitrogen into a form usable by plants, this process is termed nitrogen fixation. The value of nitrogen fixed by legume symbionts has been estimated as worth nearly $10 billion in U.S.

agriculture alone (Orrego 1981:51). Soybeans are the most valuable legume crop but others include: pea, clover, alfalfa, and peanut. The bacteria live in root modules and are provided with nutrients by the plant's vascular system and in return provide fixed nitrogen to the plant. Increased research is underway to discover bacteria-soybean combinations that will be more effective at fixing nitrogen.

Symbiotic nitrogen fixation does not take place in the major grain crops--the very ones that consume the bulk of the nitrogen fertilizer. Much research is currently underway trying to develop grains that will fix nitrogen. However, this is a long-term goal because not only must the plants be engineered to harbor the bacteria, but bacteria must also be developed to thrive in the symbiosis. This necessitates controlling the behavior and interaction of two very different organisms--a much more difficult task than engineering either one. Another difficulty is the fact that nitrogen fixation is a very energy-intensive operation. If this energy is withdrawn from grain formation, then the value of the yield lost due to energy diversion may be higher than the value of nitrogen fertilizer saved. Clearly, the promise of self-fertilizing grain crops has major hurdles to overcome.

Another area of very active research is to improve the capability of free living nitrogen fixing bacteria. These bacteria secure energy from decomposing matter and fix nitrogen into the soil. Research is directed to making these more efficient and encouraging their growth in the plant's rhizosphere so that it can utilize the newly fixed nitrogen.

The final area of research is the blue-green algae that live in the flooded rice paddy fields and can contribute 38-80 kg/ha/year to the total quantity of naturally fixed nitrogen in the paddy (Orrego 1981:57). The process of field inoculation is inexpensive, simple, and provides very good returns for the investment. Current research is focusing on the selection of varieties that can fix higher amounts of nitrogen and thrive in areas outside the plant's normal range. Another effective technology for nitrogen fixation is provided by the symbiotic relationship between a blue-green algae and the Azolla fern. In California Azolla has been introduced into paddy fields and is providing up to 75 percent of the paddy's total nitrogen requirements (Orrego 1981:58). For rice paddy culture these are very promising methods of decreasing the costs of nitrogen fertilizer use (Swaminathan 1982).

Footnotes

1) Many of the arguments in the monograph have been made in Kenney (1983), Kenney et al. (1983), Kenney et al. (1984), Kenney and Buttel (1985), Buttel et al. (forthcoming), and Kenney (forthcoming).

2) The Japanese biotechnology effort will be very important in international competition (Katzenstein and Tanaka 1984). Also, some European companies will be important biotechnology competitors (OTA 1984).

3) The chemical/pharmaceutical companies prominent in biotechnology and the Third World include: Abbott Laboratories (U.S.), American Cyanamid (U.S.), BASF (Germany), Ciba-Geigy (Switzerland), Dupont (U.S.), Hoechst (Germany), Hoffman-LaRoche (Switzerland), ICI (Great Britain), Merck (U.S.), Monsanto (U.S.), Pfizer (U.S.), Rhone-Poulenc (France), Rohm and Haas (U.S.), Sandoz (Switzerland).

4) Five to ten years is an estimate. For companies using monoclonal antibodies the delay until a marketable product emerges could be as short as two to three years. Positive cash flow for the NBFs may even take longer for some companies. Other companies such as Genentech have been able to remain near breakeven since inception due to their research contracts. There have also been a few NBFs formed in Europe. Most prominently, in the United Kingdom there are: Twyford Laboratories, Celltech, and Agritech; in France, Trangene, and the Swiss-American hybrid, Biogen.

5) It should be noted that CIMMYT (the International Center for Maize and Corn Improvement in Mexico) is also cooperating with the University of Illinois on corn improvement.

6) Biotechnology will in all likelihood facilitate the growing integration of the chemical and pharmaceutical industries in the U.S., i.e., a pharmaceutical is no more than a chemical compound or mix of compounds that must be produced in less bulk and under more rigorous standards. The desirable aspects of the pharmaceutical industry are that the products are usually patented, have higher markups, and lesser quantities are produced usually with less pollution.

The stagnation in the chemical industry with the exception of specialty and agricultural chemicals has induced U.S. MNCs to emulate European MNCs such as Sandoz, Hoechst, and Ciba-Geigy that are already integrated. Similarly, the pharmaceutical MNCs are moving into specialty and agricultural chemicals--an area of patent protection and high profitability.

7) It should be noted that yield in a farmer's field is not a simple concept. Yield must be realizable, i.e., the grain must be harvestable. Therefore, pest-resistance, drought-tolerance, and lodging-resistance are all aspects of the yield equation. Thus, yield increase also means loss minimization due to environmental factors. This leads to the economic viability of pesticide usage, etc.

8) This is a hotly debated issue with traditional plant breeders taking strong exception to this viewpoint (Sprague et al. 1980).

9) It is already the case that most hybrid seed used in Brazil, Argentina and other TWCs is either imported from developed countries or seed production in the TWC is controlled by a MNC. Companies heavily involved in this business include Pioneer, De Kalb, Sandoz, Ciba-Geigy, Upjohn, and Shell.

10) This process of shifting the public researchers out of fields in which private industry feels it can commercially exploit is a longstanding pattern in the U.S. And, in fact, is once again underway in the U.S. agricultural universities with reference to public seed release (Kloppenburg and Kenney 1983).

11) In the U.S. the artificially high price of sugar due to quotas and protectionism has certainly assisted in remaining viable. On the other hand, HFCS would probably be able to survive without the quotas. The sugarbeet industry would be destroyed.

12) Reproductive technologies applied to swine are far behind the work with cattle, but Immunogenetics (1983) claims to have developed freezing procedures for swine embryos.

13) Cell tissue culture is possible for either plant or animal cells, but for discussion focused on farming systems animal cell culture is unimportant except for the purpose of producing monoclonal antibodies (MABs) to be used for either treatment or diagnostic purposes (for example, the Molecular Genetics, Inc. scours vaccine contains MABs). Therefore, this section will be entirely devoted to plant tissue culture (PTC) for production of valuable phytochemicals.

14) It is recognized that this phased implementation might be very difficult in LDCs suffering from recurring foreign exchange problems which consistently disrupt loans. However, the other choice which is to order everything needed for the first five years immediately results in much of the equipment deteriorating before it is ever used.

15) Orrego (1983) cites figures indicating that very few of the world's practicing microbiologists are located in the TW. In examining a U.S. NIH training program for Latin Americans Orrego (1983:6) calculates that the "brain drain" to the U.S. "has varied from country to country: none for Brazil, 35% for Chile, 6% for Colombia, 2% for Mexico, and 69% for Uruguay. Finally, a survey of the memberships of the International Association of Plant Tissue Culture Association indicates that 69 countries are represented, but again the vast majority of the scientists are located in DCs with the exception of India and China. However, tissue culture is an area of increasing TW involvement (Sondahl 1984).

16) The Indian National Biotechnology Board (1983) has formed an advisory committee that includes: Dr. Narang, Canadian National Research Council; Dr. Ananda Chakrabarty, University of Illinois; Dr. Inder Verma, Salk

Institute for Biological Sciences; Dr. Satyabarla Nandi, Director, Cancer Research Institute, University of California; Dr. O. P. Bahl, Chairman, Department of Life Sciences, University of New York; Dr. K. Venkatasubramanian, Department of Chemical and Biological Engineering, Rutgers University; Dr. Sambhunath Ghosh, Manager, Bioengineering Research, Institute of Gas Technology. The ability to tap scientists of this caliber is an important strength for the Indian biotechnology program.

17) The level of interest of Indian companies may be relatively high judging from the fact that Tata Co. has entered a joint venture agreement with Kyowa Hakko Co. (Japan), Sumitomo Trading Co. (Japan) and Native Plants Inc. (USA) focusing on using biotechnology for tropical crop improvement (Tanaka 1983b).

Table 1

MIT Biology Department Faculty and Corporate Affliations

Professor	Corporation
David Baltimore	Collaborative Research
Eugene Bell	Damon Biotech
David Botstein	Collaborative Research
Herman Eisen	Damon Biotech
Gerald Fink	Collaborative Research
Har Gobind Khorana	Damon Biotech
Harvey Lodish	Damon Biotech
Irving London	Damon Biotech
Salvador Luria	Repligen
Alexander Rich	Repligen
Paul Schimmel	Repligen
Philip Sharp	Biogen
Susumu Tonegawa	Damon Biotech
David Housman	Integrated Genetics
Leonard Guarente	Biotechnica Internationa.

Source: Kenney (forthcoming)

Table 2

Agrigenetics Consultants

Consultants	Institutional Affliation
Wolfgang Dietzgen Bauer	Charles F. Kettering Research Laboratory
Andrew Binns	University of Pennsylvania
Nicholas Brewin	John Innes Institute
Adrienne Clarke	University of Melbourne, Australia
Peter Dart	Australian National University
Leon Dure, III	University of Georgia
Elizabeth Earle	Cornell University
Peter Gresshoff	Australian National University
Thomas Guilfoyle	University of Minnesota
Richard Halick	University of Colorado
Maureen Hanson	University of Virginia
Huake Hennecke	Mikrobiologishes Institut der Zurich
Thomas Hodges	Purdue University
Paul Kaesberg	University of Wisconsin
Brian Larkins	Purdue University
Sharon Long	Stanford University
Alfred Puhler	University of Bielefeld
Ralph Quatrano	Oregon State University
Barry Rolfe	Australian National University
John Shine	Australian National University
Jack Widholm	University of Illinois

Source: Agrigenetics 1983:23.

Table 3

Agricultural Biotechnology Venture Capital Firms: Principal University-Based Researchers, Financial Linkages, and Areas of Research.*

Company	Principal University-Based Researcher and Researcher's University Affiliation	Financial Linkages	Areas of Research
Agrigenetics	Dr. Timothy Hall, Univ. of Wisconsin Dr. John Kemp, Univ. of Wisconsin/USDA	Henry Ford and Rothschild Families Pioneer Group, Claeys-Luck	Seed-related biotechnologies
Advanced Genetics Science	Dr. Lawrence Bogorad, Harvard Univ. Dr. Shepard, Kansas State Univ.	Rohm & Haas	Cloning of disease-resistant potatoes
International Plant Research Institute	Formerly Dr. Martin Apple, Univ. of California, San Francisco	Davy-McKee Corp. Eli Lilly (contract) Trans KB	High yielding potatoes, saline-resistant wheat, virus-free cassava
Zoecon Corp.	Dr. Peter Carlson, Michigan State Univ.	Sandoz (formerly Occidental Petroleum)	Soybean and cotton breeding
Calgene	Dr. Raymond Valentine, Univ. of California, Davis (present status unclear)	Allied Chemical (20%)	Plant genetics
Genetic Engineering Co.	Dr. Edwin Adair, Swedish Medical Center, Denver, Dr. Thomas Wagner, Ohio Univ.		Animal genetics
DNA Plant Technology Co.	Dr. William Sharp (Campbell Soup Co.) Dr. David Evans (Campbell Soup Co.)	Campbell Soup (40%), Koppers Co., John Brown & Co., Schroder Bank	Tomatoes, tobacco, forestry products
Molecular Genetics	Dr. Burle Gengenbach, Dr. Ed Green, Dr. Ron Phillips, Dr. Joachim Messing, all of Univ. of Minnesota	American Cyanamid, Smith Kline, U.S. Dept. of Defense	Corn, scours prevention, and nonagricultural applications

*All information is accurate to the best of our knowledge, but it should be kept in mind that the proprietary nature of these firms makes it difficult to keep abreast of the latest data.

Source: Buttel et al.

Table 4

Monsanto -- Anatomy of a Biotechnology Company

In-House Investment

--$185 million invested in biological sciences research center

Biotechnology Companies (Equity Investments and Important Contracts)

Collagen -- artificial bone powder

Biogen -- tissue plasminogen activator

Genentech -- bovine growth hormone

Genex -- venture capital investment

Biotechnica International -- B. subtilis protein expression

University Contracts

Harvard University -- biomedical research ($23 million)

Washington University -- biomedical research ($23 million)

Rockefeller University -- photosynthesis research ($4 million)

Oxford University -- sugar chains ($1.5 million)

Seed Company Subsidiaries

Jacob Hartz	Monsanto Seed
Hybritech Seed Co.	Farmers Hybrid Co.

Fertilizer

5th largest U.S. producer of nitrogenous fertilizers

Pesticides

58% market share of grass herbicides market in corn (1978)
Roundup -- revenues of $500 million
Lasso -- revenues of $200 million

(Source: adapted from Buttel et al. 1983)

Table 5

In-House Corporate Life Science Research: Description and Location.*

Corporation	Area of Interest	Description	Location
Monsanto	Agriculture	$40 million invested in research	Missouri
Chevron	Agriculture	$38 million facility	California
Pfizer	Agriculture	20 Ph.D. researchers	Missouri
ARCO	Agriculture	15 scientists, 57 employees	California
DuPont	Life sciences	$85 million investment	Delaware

*These data are presented for illustrative purposes only. Other companies that have important in-house agricultural research activities include Eli Lilly, Sandoz, and Ciba-Geigy.

Table 6

Average Yields per Acre (in the U.S.) in 1930 and 1975
(from Agricultural Statistics 1930 through 1975*

Crop	1930	1975	Unit	percent increase
Wheat	14.2	30.16	bushels	115
Rice	21.0	45.6	cwt.	117
Corn	20.4	86.2	bushels	320
Oats	32.2	48.1	bushels	50
Barley	24.0	44.0	bushels	85
Grain sorghum	10.8	49.0	bushels	358
Cotton	157.0	453.0	pounds	188
Sugarbeets	11.9	19.3	tons	62
Peanuts	659.4	2565.0	pounds	295
Soybeans	13.4	28.4	bushels	112
Potatoes	65.9	251.0	cwt.	311
Tomatoes	61.0	166.0	cwt.	172
Alfalfa	1.95	2.87	tons	42

Source: Sprague et al. 1980:17.

Table 7

Possible Applications of Biotechnology Research to Rice Improvement

Research Technique	End Result
Tissue and cell culture	
Induction and selection of useful mutants at the cellular level	Salt tolerance Aluminum toxicity tolerance High lysine and high protein Low photorespiration Disease resistance Low oxygen tolerance
Embryo culture	Intra- and interspecific hybridization
Anther and pollen culture	Reducing breeding time
Protoplast fusion	Interspecific and intergeneric hybridization Hybrid rice improvement Azolla improvement
Genetic Engineering	Incorporation of nitrogen-fixing genes

Source: Swaminathan 1982:969.

Table 8

Multinational Corporations, Product Lines, and Seed Company Subsidiaries*

Multinational Parent	Primary Products	Seed Subsidiaries
Sandoz (Switzerland)	pharmaceuticals	Ladner Beta Seed (Canada) Zaadunie (Netherlands) Northrup King (USA) Rogers Brothers (USA) National-NK (USA) Sluis en Groot (Netherlands)
Shell (UK/Netherlands)	oil, chemicals	International Plant Breeders (UK) Comanie General de Semillas (Spain) Rothwell Group (UK) Interseeds (Netherlands) IPB Japan (Japan) Nickerson P. Gmbh (West Germany) Zwaan (Netherlands & Belgium) North American Plant Breeders (USA; with Olin Chemical)
CIBA-Geigy (Switzerland)	pharmaceuticals, chemicals	Funk Seeds International (USA) Stewart (Canada) Louisiana Seeds (USA) CIBA-Geigy Mexicana (Mexico)
Celanese (USA)	textiles, chemicals	Celpril (USA) Moran (USA) Joseph Harris (USA) Nugrain
Cargill (USA)	grain marketer	ACCO (USA) Dorman (USA) Kroeker (Canada) PAG (USA)
Occidental Petroleum (USA)	oil, petrochemicals	Ring Around Products (USA) Excel Hybrid (USA) Missouri (USA) Moss (USA)

*All information is accurate to the best of our knowledge, but it should be kept in mind that the proprietary nature of these firms makes it difficult to keep abreast of the latest data.

Source: adapted from Buttel et al. 1983

Table 9

Animal Disease Vaccines Being Developed Using Biotechnology*

Vaccine	Company
Bovine scours	Molecular Genetics Inc. Cetus
Porcine scours	Cetus Molecular Genetics Inc.
Foot and Mouth Disease	Genentech Biogen Molecular Genetics Inc.
Porcine Parvovirus	Molecular Genetics Inc.
Pseudorabies	Molecular Genetics Inc.
Bovine viral diarrhea	Molecular Genetics Inc.
Bovine adenovirus	Molecular Genetics Inc.
Infectious bovine rhinotracheitis	Molecular Genetics Inc.
Rift Valley Fever	Molecular Genetics Inc. (under contract from the U.S. Department of Defense)

* These data are accurate to the best of the author's knowledge, but do not constitute a recommendation or evaluation of efficacy.

Source: Author's compilation from various sources.

Table 10

Plant Product Tissue Culture: Performing Corporation and Country of Origin.*

Product	Company	Country of Origin or Cultivation
Opium	Plant Science (UK)	Turkey, Thailand
Cinchona	Plant Science (UK)	South America, Indonesia
Digitalis	Plant Science (UK)	
Ginseng	Plant Science (UK)	United States, Korea
Catharanthine	Institute for Biotechnology Research (Ger)	
Pyrethrum	Biotec (Bel)	Kenya, Tanzania, Uganda
Tobacco	Japanese Salt and Tobacco Monopoly	United States
Murasaki	Mitsui Petrochemical (Jap)	Japan, Korea, China

*These data are presented for illustrative purposes only.
Source: Buttel et al. 1983

Table II
Examples of Cooperative Biotechnology Efforts Between
Less Developed and Developed Countries*

Less Developed Country	Small Company	Area of Research
Malaysia (Sime Darby Berhad)	International Plant Research Institute (USA)	plantation crops
Argentina	Molecular Genetics (USA)	testing FMD vaccine
China	Biogen (Switzerland)	interferon
China	Biotech Research Labs (USA)	monoclonal antibody diagnostics
China	Promega Biotech (USA)	enzymes and reagents
Korea (Cheil Sugar Co.)	Eugene Tech, Inc. (USA)	interferon
Korea (Lucky Limited)	Chiron Corp (USA)	interferon
India (Tata Ltd.)	Native Plants Inc. (USA)	tea, coffee, cocoa improvement
Brazil	DNA Plant Technologies (USA)	sugarcane and coffee improvement

* Data accurate to best of author's knowledge.

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